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# Truetime MK-V 151-301-522 P/Y Code GPS Receiver Live Static Test

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## EXECUTIVE SUMMARY

The Global Positioning System (GPS) Joint Program Offices (JPO), Los Angeles Air Force Base, California, has established a Center of Expertise (COE) comprised of several agencies each providing unique GPS receiver test capabilities. The Responsible Test Organization (RTO) for the COE is the 746th Test Group, 46th Guidance Test Squadron, Holloman Air Force Base, New Mexico. The Naval Research Laboratory (NRL) has been designated as the Participating Test Organization (PTO) with the responsibility of testing the Precise Time and Time Interval (PTTI) characteristics of both commercial and military GPS receivers<sup>1</sup>.

The Defense Information System Agency (DISA) operates several hundred communication sites throughout the world. These sites have a requirement for precision frequency standards. Loran-C frequency receivers have been used successfully for many years at these DISA communication sites. With the advent of GPS the U.S. Coast Guard discontinued its worldwide management of the Loran system. In 1992 the GPS JPO, acting as the Lead Military Department for procurement of the DISA receiver, selected Quantic Industries to deliver Precise Position Service (PPS) C/A code Timing GPS Receivers (TGR) to be used to replace the DISA Loran-C receivers. These receivers were originally scheduled to be delivered during the summer of 1993. In September 1994, because of the lengthy technical delays, DISA decided it could no longer wait for the Quantic GPS receivers. Instead they purchased and fielded 270 GPS receivers from Truetime, Inc. Model GPS-DC-MARK III (MK III) which was tested by NLR<sup>2</sup>. These receivers are being upgraded by Truetime Inc. to the Truetime MK-V 151-301-522 P/Y CODE (MK-V) keyed receiver to satisfy the DOD requirement that the receivers be capable of removing selective availability (SA) inaccuracy. This receiver is similar the Truetime MK-V P/Y CODE series of keyed receivers manufactured by Truetime, Inc.

Testing of the receiver was completed in the spring of 1997. The test results in this report apply only to this model receiver. A series of long term time and frequency measurements were to see how close the Truetime receiver came to meeting the original TGR specifications.

The Truetime MK-V tested at NRL was found to meet most of the TGR time and frequency performance specifications, and meets all the TGR frequency stability specification. One additional test that was performed on the MK-V and not on the MK III was the replacement of the coax cable by a 1 kilometer fiber optic link between the antenna and receiver. The fiber optic link allows for long leads between the antenna and receiver and introduced a negligible amount of noise to the signal.

The Truetime MK-V one pulse per second time output was also found to be lagging GPS time by  $64.01 \pm 4.75$  nanoseconds. It possible to calibrate the receiver so that it would out put time to within  $\pm 10$  nanoseconds. The TGR specifications requires a 10 volts peak level for the one pulse per second signal whereas the MK-V produced only a TTL pulse. The MK-V phase noise floor was above the TGR specification of -135 dBc between 100 to 1000 Hz.



## **TRUETIME MK-V 151-301-522 P/Y CODE GPS RECEIVER LIVE STATIC TEST**

### **1. INTRODUCTION**

The Global Positioning System (GPS) Joint Program Offices (JPO), Los Angeles Air Force Base, California, has established a Center of Expertise (COE) comprised of several agencies each providing unique GPS receiver test capabilities. The Responsible Test Organization (RTO) for the COE is the 746th Test Group, 46th Guidance Test Squadron, Holloman Air Force Base, New Mexico.

The Naval Research Laboratory (NRL) has been designated as the Participating Test Organization (PTO) with the responsibility of testing the Precise Time and Time Interval (PTTI) characteristics and accuracy of both commercial and military GPS receivers. NRL has a precision clock evaluation facility (PCEF) with time and frequency traceable to the U.S. Naval Observatory (USNO) Universal Time Coordinated (UTC). The test procedures used by NRL are taken from the COE's CORE Inertial Navigation System/GPS Receiver/Embedded GPS-INS (INS/GR/EGI) Test Plan<sup>1</sup> and from NRL's internal test plan<sup>3</sup> prepared as a COE member.

The Defense Information System Agency (DISA) operates several hundred communication sites throughout the world. These sites have a requirement for precision frequency standards. Loran-C frequency receivers have been used successfully for many years at these DISA communication sites. With the advent of GPS, the U.S. Coast Guard discontinued its worldwide management of the Loran system. In 1992 the GPS JPO, acting as the Lead Military Department for procurement of the DISA receiver, selected Quantic Industries to deliver Precise Position Service (PPS) C/A code Timing GPS Receivers (TGR) to be used to replace the DISA Loran-C receivers. These receivers were originally scheduled to be delivered during the summer of 1993. In September 1994, because of the lengthy technical delays, DISA decided it could no longer wait for the Quantic GPS receivers. They purchased and fielded 270 MK-III receivers from Truetime, Inc. instead. These receivers are being upgraded by Truetime Inc. to the Truetime MK-V Model 151-301-522 P/Y CODE (MK-V) keyed receiver to satisfy the DOD requirement that the receivers be capable of removing selective availability (SA) inaccuracy. This receiver is similar the Truetime MK-V P/Y CODE series of keyed receivers manufactured by Truetime, Inc.

A Truetime MK-V (SN#86141192) keyed receiver was tested at NRL to certify and validate the receiver's performance for use as an alternative to the Quantic TGR. A series of long term time and frequency measurements were made over the next year to see how close the Truetime unit came to meeting the original TGR specifications. The MK-V was only tested in the keyed mode only.

An additional test was made replacing the coax cable antenna lead from the antenna to the receiver with a one Kilometer long fiber optic antenna cable and measure any introduction of additional phase noise. The fiber optic link was made by Ortec Corporation<sup>4</sup> using their fiber optic transmitter and receiver, model 3111A-002 and 4111A-002 respectively with a frequency range of 950 to 1750 MHz.

### **1.1 Test Item Description**

The Truetime MK-V GPS receiver is designed to provide precise time and frequency that is traceable to USNO. The MK-V receiver uses the L1 (1575.42 Megahertz) Coarse Acquisition (C/A) code signal to acquire the P/Y code provided by the NAVSTAR GPS satellites. When keyed, the MK-V will use Y code L1 or L2 (1227.6 Megahertz) signals.

The MK-V has been designed to be completely automatic in satellite signal acquisition. Whenever the site position information is not known to within the required accuracy of less than  $\pm 25$  meters, it will be necessary to track four satellites to allow the MK-V to determine its antenna position. From that point on, the MK-V will require only one satellite to maintain valid time. However, operation to the specified frequency stability requires four or more satellites. When no satellites are in view, the MK-V will continue to output its PTTI signals using the internal disciplined oscillator.

The internal oscillator is a highly accurate frequency source with excellent short term stability and very good holdover performance during periods when GPS satellites are not usable. While GPS satellite data is available, the GPS-XL microprocessor controls this oscillator via a 16 bit Digital Analog Converter (DAC) in such a way as to phase lock its output to UTC.

The MK-V produces precise time in the form of an IRIG-B time code which was not evaluated in this report and a one pulse per second (PPS) signal. The MK-V has three frequency outputs (1, 5 and 10 MHz). and has the ability to measure an external frequency source. A discrete fault indicator is included to let the user know if the receiver is operating normally. The interface layout can be seen in (figure C.1).

## **2. TEST OBJECTIVES**

Evaluate the frequency and timing performance of Truetime MK-V, Model 151-301-522-P/Y receiver with respect to the vendor and TGR specifications. The specific test objectives are summarized below. Detailed test results on the MK-V receiver are contained in Appendix D.

## 2.1 Performance Evaluation, Specifications, Test, And Document Paragraph Matrix

Table 1 provides a matrix of the paragraph numbers where the MK-V performance specification, test description, test results and TGR performance specification can be found. A comparison of the TGR performance specifications and the performance specifications to the MK-V test results are made in the test result paragraphs.

Test Objective: Evaluate	MK-V Performance Specification Paragraph	MK-V Test Description Paragraph	MK-V Test Result Paragraph	TGR Performance Specification Paragraph
Self Survey Accuracy	E.1	3.1	4.1	B.1
Timing Accuracy	E.2	3.2	4.2	B.2
One Pulse-Per-Sec Output	E.3	3.3	4.3	B.3
Spurious And Harmonic GPS Content	E.4	3.4	4.4	B.4
Phase Noise Measurements	E.5	3.5	4.5	B.5
Frequency Accuracy	E.6	3.6	4.6	B.6
Frequency Stability	E.7	3.7	4.7	B.7

Table 1. Matrix of Test Objectives Paragraph Numbers

## 3. TEST DESCRIPTIONS

The MK-V receiver is PPS capable so the errors induced by selective availability (SA) are removed during these test. All tests were performed using reception from live operational satellites. Details of measurement methods and test equipment used are presented in Appendix A. Testing started during the summer of 1996 and was concluded in spring of 1997.

### 3.1 Position

The receiver's GPS antenna was placed near NRL's Defense Mapping Agency (DMA) bench mark on the roof of NRL building 53.

### 3.2 Time Accuracy

The Truetime MK-V One Pulse Per Second (1PPS) timing output was measured against the NRL time scale. This time scale is traceable to USNO (UTC) to within a few nanoseconds.

### 3.3 1PPS Output

Pulse width, rise and fall times, peak voltage, and overall wave form of the 1PPS were displayed on a Giga-sample digital sampling storage oscilloscope and recorded.

### 3.4 Spurious And Harmonic Content

The 5 MHz sine wave output on the rear panel (see figure C.1) was checked for spurious and harmonic signals.

### 3.5 Phase Noise Measurements

The 5 MHz sine wave output on the rear panel (see figure C.1) was examined for phase noise and spurious content from DC to 100 KHz.

### 3.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to the NRL house frequency reference Hydrogen Maser was measured. The NRL maser frequency is then referenced to the USNO Master Clock.

### 3.7 Fractional Frequency Stability

Phase difference data between the NRL N1 Maser and the MK-V 5 MHz sine wave output were recorded. This data was then used to calculate the frequency stability of the MK-V in the form of the Allan Deviation.

## 4. TEST RESULTS

A brief synopsis of the results of the tests is presented in the following paragraphs. Detailed descriptions of the results as well as graphs of wave forms and measurements are provided in Appendix D.

### 4.1 Position

The Truetime MK-V GPS antenna was installed on the roof of NRL building 53, at a Defense Mapping Agency (DMA) bench mark. Position coordinate errors are listed in table 2. The MK-V position error, specifications, and comparison to TGR are shown in table 3.

Dimension	Receiver derived position WGS-84	Receiver true position WGS-84	Error
height	-21 m	-19.676 m	-1.32 m
latitude	N 38° 49' 14.6"	N 38° 49' 14.46"	N 4.32 m
longitude	W 77° 01' 28.3"	W 77° 01' 28.40"	E 2.41 m

Table 2. Position Error Measurements

Receiver	Spherical Error, RSS	Specification
MK-V	5.12 m	< 3 m
TGR	3.1 m typical	< 5 m

Table 3. MK-V receiver comparison with the TGR receiver specifications in the keyed mode.

## 4.2 Timing Accuracy

A detailed calibration of all MK-V timing system errors were completed. The MK-V 1PPS time signal, when averaged over time intervals of 24 hours, and covering a period of three months was found to be lagging USNO time by  $64.01 \pm 4.75$  nanoseconds. A segment of this data is shown in figure D.1. The GPS scale is steered<sup>6</sup>, as needed, on a daily basis to be within one microsecond of UTC(modulo one second).

## 4.3 One Pulse-Per-Second Output

The output 1PPS is a TTL-type logic level compatible, positive-going, 20 microsecond wide pulse when driving a 50 ohm load impedance. Table 4 contains a summary of these measurements. The full pulse is shown in figure D.2 with an amplitude of 3.4 volts with a slight overshoot. Figure D.3 shows that the MK-V 1PPS timing signal has a very fast rise time of less than 1 nanosecond. The fall time is shown in figure D.4, also less than 1 nanosecond. Figure D.5 shows unwanted EMI leakage from the IRIG circuitry that bleeds into the 1PPS output.

	Amplitude	Rise time	Fall Time	Pulse Width
MK-V Measurement	3.4 V	< 1 ns	< 1 ns	20 us
TGR Specification	10 V $\pm$ 10 %	< 20 ns	< 1 us	20 us $\pm$ 5%

Table 4. Characteristics of the 1PPS

## 4.4 Spurious And Harmonic Content

The Truetime MK-V primary frequency outputs have a signal level of + 13 dBm, figure D.6 shows the 5 MHz output and its harmonic content out to 50 MHz. Numerous unwanted frequency spurs can be seen in figures D.7 and D.8 but all are within specification. The noise floor shown in figure D.8 is not correct because the dynamic range of the spectrum analyzer has been exceeded. The summary of the test results are shown in table 5.

	Spurious 5 MHz	Harmonic 5 MHz
MK-V Specification	Not Specified	Not Specified
TGR Specification	-60 dBc @ 1 MHz	-40 dBc
MK-V Measured	-75.9 dBc	-57.9 dBc, 1st Har

Table 5. Spurious And Harmonic Content

#### 4.5 Phase Noise Measurements

The 5 MHz sine wave output on the rear panel was examined for phase noise and spurious content. The MK-V receiver has a phase noise floor at -120 dBc at 1 KHz with a number of spurs that can be seen in figures D.9 through D.13. A comparison of phase noise between copper coax cable and fiber optic cable between the antenna and receiver shows no difference in phase noise. The MK-V fails to meet the TGR phase noise specification between 100 to 1000 Hz. General results are shown in table 6 for copper coax only.

Frequency	10 Hz	100 Hz	1 KHz	100 KHz
MK-V Specification	None	None	None	None
TGR Specification	-87 dBc/Hz	-120 dBc/Hz	-135 dBc/Hz	None
MK-V Measured	-120 dBc/Hz	-120 dBc/Hz	-120 dBc/Hz	-127 dBc/Hz

Table 6. Phase Noise

#### 4.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to USNO was measured. The data is shown in figure D.14 with the results shown in table 7. The MK-V frequency measurement value is the result of data averaged from (10) 3 hour averaging periods per the TGR SCN-3 specifications.

	Specifications	Measured
MK-V	$3 \times 10^{-12}$	$8.60 \times 10^{-14}$
TGR	$2 \times 10^{-12}$	Not Applicable

Table 7. Frequency Accuracy

#### 4.7 Fractional Frequency Stability

Phase data was taken from the 5 MHz sine wave output at one second intervals for one hour and at one hour intervals over 64 days for both using a regular coax cable (copper) and a fiber optic cable (fiber). These data sets were used to calculate the Allan Deviation for sample periods of between 1 and 500,000 seconds with the results given in table 8 and figures D.15 and D.16. Figure D.17 is the Allan Deviation of the true time MK III unkeyed timing receiver which does not satisfy the TGR specifications over one portion of the curve. The MK-V receiver met all the TGR frequency stability specifications.

Sample Interval, Seconds	1	10	100	1,000	10,000	Day
MK-V Specification	$1 \times 10^{-11}$	$1 \times 10^{-11}$	$2 \times 10^{-11}$	$2 \times 10^{-11}$	$2 \times 10^{-12}$	$2 \times 10^{-13}$
TGR Specification	$1 \times 10^{-10}$	None	$1.5 \times 10^{-11}$	$1.0 \times 10^{-11}$	$7.0 \times 10^{-12}$	None
MK-V Measured Copper	None	None	$1 \times 10^{-11}$	$3.4 \times 10^{-12}$	$6.3 \times 10^{-13}$	$8.9 \times 10^{-14}$
MK-V Measured Fiber	None	None	None	$4 \times 10^{-12}$	$6.4 \times 10^{-13}$	$1.4 \times 10^{-13}$

Table 8. Allan Deviation.

#### 4.8 Conclusions

The Truetime MK-V tested at NRL was found to meet all of the TGR time and frequency performance specifications. The Truetime MK-V one pulse per second time output was found to be lagging GPS time by  $64.01 \pm 4.75$  nanoseconds. Once calibrated the MK-V would output the correct time to within  $\pm 10$  ns after a few minutes of averaging time. The TGR specifications requires a 10 volt peak level for the one pulse per second signal whereas the MK-V produced only a TTL pulse which is not considered serious. The MK-V phase noise floor was 15 dB above the TGR specification of -135 dBc at 1 KHz.

While still not meeting all of the original TGR specifications the Truetime MK-V should still make a good replacement for the Loran-C receivers. The Truetime MK-V is a solution due the fact that the DOD may require that all GPS receivers used be PPS-Y code capable in the near future.

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## Appendix A

### MEASUREMENT METHODS

#### A.1 TIME CALIBRATION

The time and frequency references used at the NRL Precise Clock Evaluation Facility (PCEF) are two Sigma Tau hydrogen masers. These masers produce both one pulse per second (1PPS) and a 5 MHz sine wave frequency reference signals that are synchronous with UTC(USNO). The traceable characterization of the reference 1PPS is accomplished using a "traveling clock" procedure augmented by continuous phase monitoring at NRL. First a measurement is made of the time epoch between NRL's Maser and a mobile HP-5071 Cesium Frequency Standard "traveling clock". Then this Cesium is transported to USNO and compared with their Master Clock and then returned to NRL again for a final comparison called clock closure. This procedure produces two difference equations. Simultaneous solution of these difference equations removes the "traveling clock" and produces the time difference between the NRL's Maser and the USNO's Master Clock.

To monitor the accumulated phase difference during periods between traveling clock trips, a continuous phase monitoring system is employed<sup>5</sup> (see diagram A.1). This system uses "common viewing" of a local television station (WTTG-TV5) carrier frequency. Both USNO and NRL monitor its signal with closure over a phone link. At each site the television carrier signal is mixed with a frequency derived from the in local primary frequency standard. The difference frequency at each location is a 2250 Hz beat tone. The USNO beat tone is transferred to NRL via a dedicated phone line. At NRL, this beat tone is compared with a similarly derived beat tone to produce the phase difference between the USNO Master Clock and NRL's Maser. Combined with the traveling clock data, an estimate of the absolute time error between each location is maintained to less than two nanoseconds.

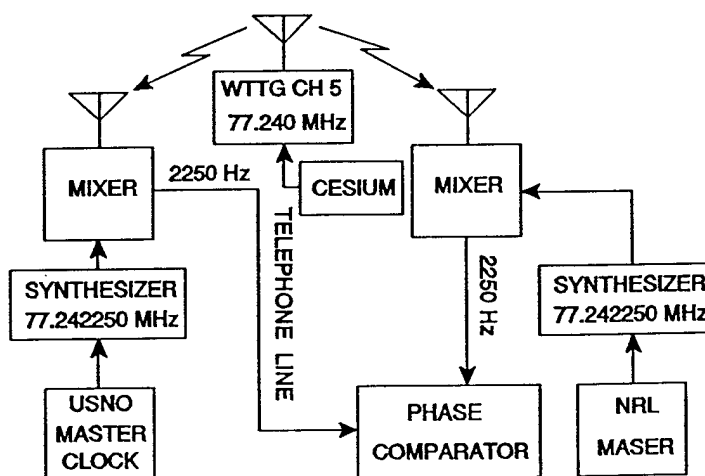


Diagram A.1. TIME CALIBRATION

## A.2 ANALYSIS AND MEASUREMENTS

The Truetime's 1PPS was connected to the NRL 1PPS measurement system. This measurement system is capable of measuring sixteen input channels sequentially with 20 picoseconds single shot resolution at a sample interval of five minutes.

The receiver's 5 MHz output was connected to NRL's short and long term phase measurement systems, see figure A.2. The short term system is capable of measuring 12 inputs simultaneously, using dual mixer techniques, at a  $\tau$ -interval of 20 seconds. It has a system noise floor of  $6 \times 10^{-12}$  over  $\tau$ . The long term system is capable of measuring 48 inputs simultaneously. It too, uses dual mixer techniques, at a  $\tau$ -interval of one hour. It has a system noise floor of  $6 \times 10^{-12}$  over  $\tau$ . These systems together provided intermediate and long term fractional frequency data.

## A.3 LIST OF TEST EQUIPMENT

The receiver's RF output was tested for phase noise and spurious signals using an extremely low noise test suite of equipment. Consisting of an HP 3562 Dynamic Signal Analyzer, a FemtoSeconds FSS 1000, and an HP 10 MHz crystal, the system measured the single sideband phase noise,  $\mathcal{L}(f)$ , from DC to 100 kHz. Spurious response was documented using an HP 8563 Spectrum Analyzer. All these systems taken together provided the necessary information about the receiver's precision time and frequency outputs. A complete list of the equipment used is shown below. A block diagram of the measurement system and how it connects to the Truetime MK-V is shown in Diagram A.2.

- IBM-AT 486 Computer used for serial data collection (Not shown)
- FemtoSeconds Phase noise Detector FSS 1000
- Hewlett Packard 10 MHz Quartz Oscillator
- Hewlett Packard 3562 Dynamic Fast Fourier Transform Signal Analyzer (FFT)
- Hewlett Packard 8753 Network Analyzer (Not Shown, Used To Measure Cable Delays)
- Hewlett Packard Digital Oscilloscope 54111D
- Hewlett Packard Spectrum Analyzer 8563A
- Hewlett Packard Digital Synthesizer 3325
- Time System Technology (TST), Inc. 6460 Clock
- Sigma Tau Maser

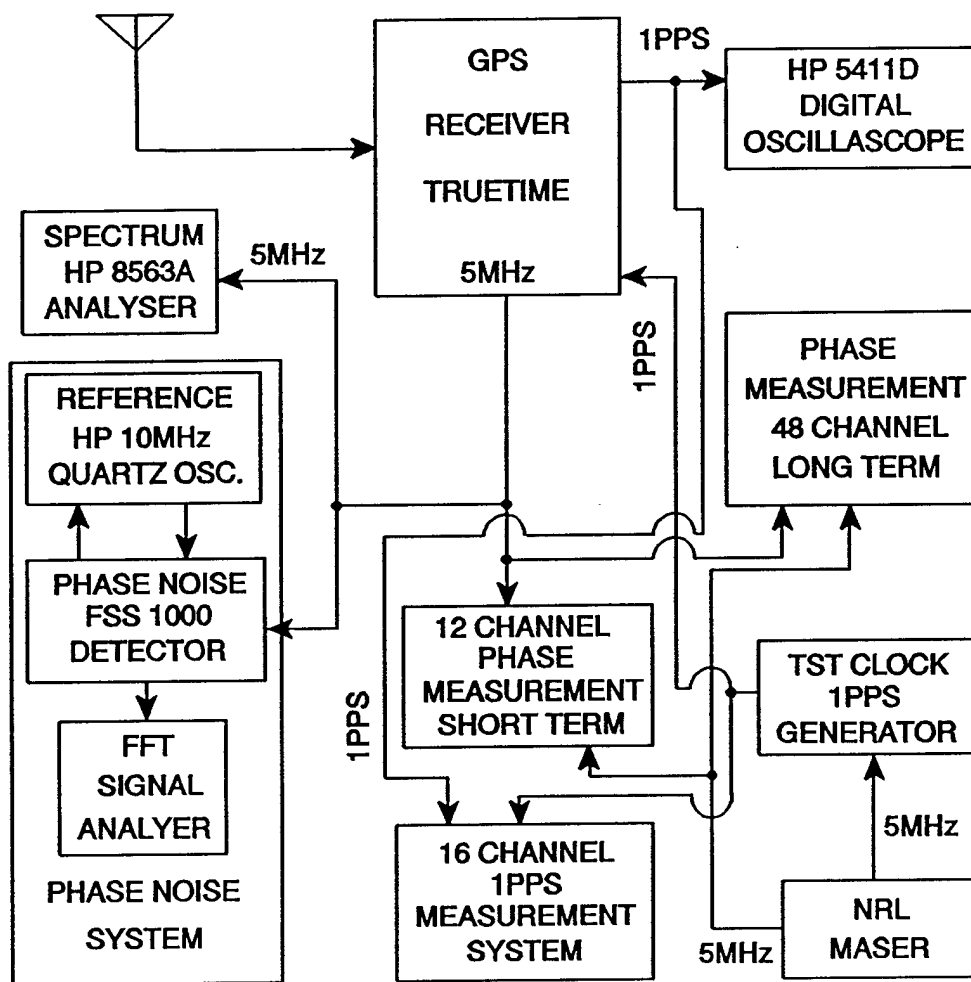


Diagram A.2. Precision clock evaluation facility.

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## **Appendix B**

### **TGR SPECIFICATIONS (SCN-3)**

The TGR specifications<sup>6</sup> are copied directly from the manual along with their section number as listed in the manual.

#### **B.1 SELF SURVEY ACCURACY**

##### **3.2.1.1.5.2 Position Determination**

The TGR shall be capable of determining the position of its antenna phase center in the World Geodetic System - 1984 (WGS-84) datum. Following operator command, or automatically, position determination shall be accomplished without requiring operator action. The TGR shall meet the frequency and time requirements when the position is determined by the TGR set or when a position is entered manually from a surveyed position accurate to within a 5 meters or less radial error. Manual entry of position data shall be entered as altitude, latitude and longitude and shall override any previous position computed or entered.

#### **B.2 TIMING ACCURACY**

##### **3.2.1.1.1 1PPS Transfer Accuracy**

Transfer accuracy relative to UTC (or GPS, if selected) Time shall be less than 100 ns RMS whenever one or more satellites are being tracked and the TGR antenna is positioned as described in paragraph 3.2.1.1.4.

#### **B.3 ONE PULSE PER SECOND OUTPUT**

##### **3.2.2.1.2.2.2 Pulse Width**

Pulse width shall be 20 microseconds  $\pm$  5 percent. The rise time shall be less than 20 nanoseconds and the fall time shall be less than one microsecond, as illustrated in MIL-STD-188-115

##### **3.2.2.1.2.2.1 Output Voltage**

The pulse amplitude shall be between 10 volts  $\pm$  10 percent and 0 volts  $\pm$  1 volt, as illustrated in MIL-STD-188-115.

#### **B.4 SPURIOUS AND HARMONIC CONTENT**

##### **3.2.2.1. Time, Frequency, and Control Inputs and Outputs**

###### **a. Harmonic Distortion**

As specified in MIL-STD-188-155, The harmonic distortion for the sine wave signal shall be at least 40 dB below the rated output level. The level of any signal

component not a harmonic of the signal frequency shall be at least 60 dB below the rated output level.

## **B.5 PHASE NOISE MEASUREMENTS**

### **3.2.2.1 Time, Frequency, and control Inputs and Outputs**

#### **b. Phase Noise**

The following specification shall be met at all times after a 1 hour warm up period:

- > - 87 dB @ 10 Hz from carrier
- > - 120 dB @ 100 Hz from carrier
- > - 135 dB @ 1 KHz from carrier

## **B.6 FREQUENCY ACCURACY**

### **3.2.1.1.2 Frequency Accuracy**

When the TGR is operating with outputs disciplined to GPS and is tracking satellites, the frequency accuracy shall be better than  $1.0 \times 10^{-11}$  RMS, when computed from a set of 9 frequency measurements, each measurement being averaged over one of 9 consecutive 10,000 second intervals.

## **B.7 FREQUENCY STABILITY**

### **3.2.1.1.3 Frequency Stability**

The frequency stability shall meet or exceed the following specifications:

- |                              |  |
|------------------------------|--|
| 1 sec (Allan var.) avg:      | $1.0 \times 10^{-10}$                              |
| 100 sec (Allan var.) avg:    | $1.5 \times 10^{-11}$                              |
| 1000 sec (Allan var.) avg:   | $1.0 \times 10^{-11}$                              |
| 10,000 sec (Allan var.) avg: | $7.0 \times 10^{-12}$ **                           |
| Frequency drift/day:         | $5.0 \times 10^{-10}$ (after loss of GPS tracking) |
- \* \* minimum of 10 pairs, non overlapping

## Appendix C

### TRUETIME MK-V RECEIVER MODEL 151-301-522-P/Y SPECIFICATIONS

The Truetime MK-V Model 151-301-522-P/Y (MK-V) receiver specifications are copied directly or abstracted from the TRUETIME manual<sup>7</sup>. The layout of the front and rear panels of the MK-V receiver is shown in figure C.1.

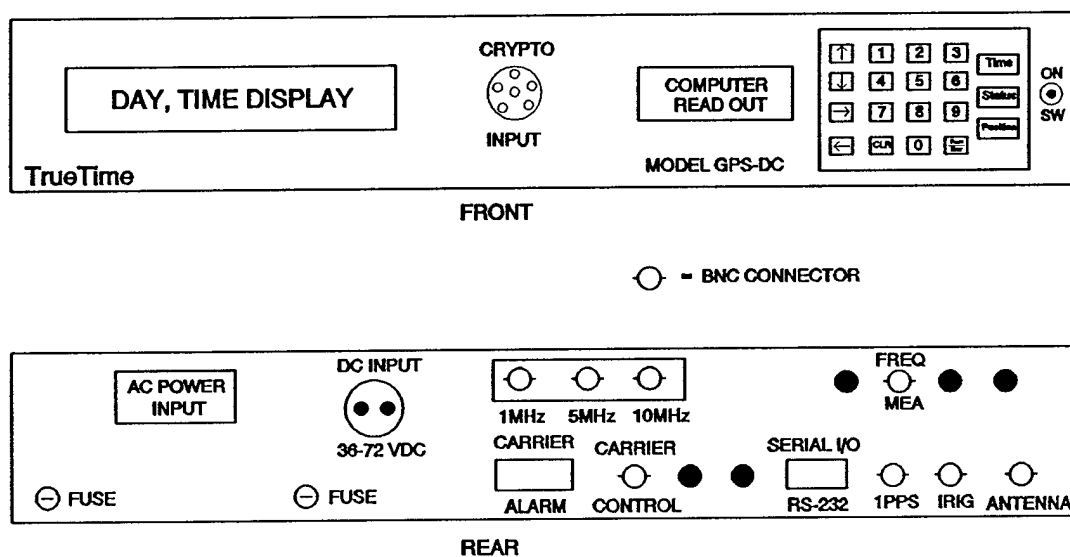


Figure C.1. TRUETIME receiver front and rear view.

#### C.1 SELF SURVEY ACCURACY

Position Accuracy: Latitude, longitude, altitude within 25 m (SEP) for a single fix referred to WGS84 when sequentially tracking four (4) or more satellites with a PDOP  $\leq 6$ . If SA is being transmitted, the two dimensional RMS is 100 meters. The 24 hour averaged position accuracy is  $< 10$  m.

#### C.2 TIMING ACCURACY

GPS Time  $\pm 150$  ns.

UTC(USNO)  $\pm 150$  ns.

Both specifications are valid when the antenna's geodetic position is known within 25 m and one satellite is being tracked.

### C.3 ONE PULSE PER SECOND OUTPUT (STANDARD)

Pulse width: 20uS  
On time edge: Positive rising.  
Amplitude: TTL Levels into 50 ohms.  
Drive: 50 ohm.  
Connector: Rear panel BNC.

### C.4 SPURIOUS AND HARMONIC CONTENT

Harmonic distortion: -50 dBc from 5 MHz sine wave output.  
Spurious not specified

### C.5 PHASE NOISE MEASUREMENTS

\*\*None specified.

### C.6 FREQUENCY ACCURACY

Frequency Output Accuracy:  
Less than  $3 \times 10^{-12}$

### C.7 FREQUENCY STABILITY

Frequency/Timing stability when tracking satellites:

Allan Deviation

$1 \times 10^{-9}$	@	1 sec
$3 \times 10^{-10}$	@	10 sec
$3 \times 10^{-10}$	@	100 sec
$3 \times 10^{-12}$	@	100000 sec

Oscillator Temperature Coefficient (Disciplined High Stability Quartz Oscillator):  
<  $1 \times 10^{-10}/^{\circ}\text{C}$  when not tracking satellites.

Oscillator stability:  
 $2 \times 10^{-9}$  over  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  when not tracking satellites.



## Appendix D

### DESCRIPTION OF TEST RESULTS

#### D.1 TEST DESCRIPTION

All test were performed with the receiver in the auto/time transfer mode and using live satellites. Testing began on the first version of the Truetime MK-V in the summer of 1996 and testing of the finial fielded unit was completed in spring of 1997.

##### D.1.1 Position

The antenna was installed on the roof of NRL building 53 two meters (m) above the NRL bench mark. The Defense Mapping Agency (DMA) calibrated height of the NRL bench mark is -18.15 m World Geodetic Survey, 1984 (WGS-84). The corrected height of the TRUETIME antenna is -16.15 m WGS-84. The antenna has a low noise pre-amplified L1 band antenna section and a built in down converter. The receiver was turned on and allowed to warm up for 12 hours. The approximate longitude and latitude of the receiver's antenna was loaded into the receiver, and the receiver was then allowed to self-survey the antenna location for 24 hours. The MK III then stores this average self-survey in non-volatile memory and automatically switches to TIME mode. Position coordinate errors are listed in table D.1. To establish an upper bound on timing errors due to position uncertainty, the Root-Squares-Summed (RSS) was computed to be 4.2 meters. The nominal timing error due to these position errors would be about 14 nanoseconds (ns). This error is small when compared to the effect of SA on the GPS derived time signal.

Dimension	Receiver software position WGS-84	True antenna position WGS-84	Error
height	-15 (m)	-16.15 m	-1.15±0.5 m
latitude	N 38° 49.2367'	N 38° 49.2363'	S 0.74±1.5 m
longitude	W 77° 01.465'	W 77° 01.4676'	W 3.75 ±1.2 m
Error RSS			4.2 ±1.98 m

Table D.1. Position Measurements

### D.1.2 Time Accuracy

A detailed calibration of all MK-V timing system errors were completed. The MK-V antenna cable delay was measured to be 125.2 nanoseconds. The delay from the receiver's time output to the NRL measurement system was measured to be 193.8 nanoseconds. The calibration cable introduced a 30.5 ns delay. The total delay is given by

$$-125.2 - 193.8 + 30.5 = -288.5 \text{ ns.}$$

This delay is subtracted from the receiver time output and gives values in the range of -63 ns. Figure D.1 shows the time output measured against USNO for two days and gives an average offset value of  $-64.01 \pm 4.75$  ns. If the receiver's offset were calibrated it may be possible to obtain time to within  $\pm 10$  ns after several minutes of averaging.

### D.1.3 One Pulse Per Second Characterization

The output 1PPS is a TTL-type logic level compatible, positive-going, 20 microsecond wide pulse when driving a 50 ohm load impedance. The full pulse is shown in figure D.2 with an amplitude of 3.4 volts with a slight overshoot. Note the output level is not 10 volts peak pulse as requested in the TGR specifications. Figure D.3 shows that the MK-V 1PPS timing signal has a very fast rise time of less than 1 nanosecond. The fall time is shown in figure D.4, also less than 1 nanosecond. Figure D.5 shows unwanted EMI leakage from the IRIG circuitry that bleeds into the 1PPS output.

### D.1.4 Spurious And Harmonic Content

The 5 MHz RF output (see figure C.1) of the receiver was checked for spurious and harmonic signals. Figure D.6 shows the 5 MHz primary output at a level of +13.1 dBm along with its integer harmonics out to 50 MHz. The amplitude of the receiver's harmonic content is much less than required by the TGR specification.

Figure D.7 is a plot of the frequency spectrum from 100 kHz to 4.95 MHz using a quarter-wave trapping stub to attenuate the main 5 MHz signal. This method increases the dynamic range of the analyzer and pulls small signals out of the analyzer system noise. Note the crosstalk into the 5 MHz output coming from the 1 MHz frequency output displayed in this plot. Also note the numerous frequency components approaching the fundamental. These are believed to be Amplitude Modulation artifacts from a 78 kHz signal detected in the single sideband phase noise plots shown later in this paper. All observed discrete frequency components were well below the manufacturer's and TGR specifications.

Figure D.8 is the broadband spectral plot also using the quarter wave trap. Note the group of frequencies around the 30 MHz region. They have no obvious source but are well below the TGR and the Truetime specifications.

### D.1.5 Phase Noise Measurements

The 5 MHz sine wave output on the rear panel was examined for phase noise and

spurious content. All figures are in units of dB below carrier, dBc or  $L(f)$  and are made from the NRL single sideband phase noise measurement system. The MK-V receiver has a phase noise floor at -120 dBc at 1 KHz with a number of spurs that can be seen in figures D.9 through D.13. Figure D.9 is the phase noise measurement with the antenna fiber optic (fiber) cable connected and can be compared to the phase noise in figure D.10 for a copper coax (copper) and shows no increase in phase noise. Figure D.9 is free of any unusual signals, even around the 60 Hz area where power line interference usually occurs. Figure D.10 shows the phase noise of a copper antenna cable with the drawn in TGR specification line out to 100 Hz with a peak at 90 Hz of unknown origin. Figure D.11 shows the phase noise of a copper antenna cable out to 10 KHz and the MK-V does not satisfy the drawn in TGR phase noise specification between 100 and 1000 Hz. Figure D.12 shows the phase noise to 10 KHz with the fiber antenna cable connected and figure D.13 shows the phase noise copper antenna cable out 100 KHz. There is very little or no increase in the phase noise by replacing the copper with a fiber cable. The 1PPS timing signal is clearly shown bleeding over into the frequency output in figure D.9. A particularly large peak can be seen in figure D.13 at about 48 kHz and this may be due to the receivers switching power supply.

#### D.1.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to USNO was measured and the data is shown in figure D.14. The MK-V frequency offset measurement of  $8.60 \times 10^{-14}$  is the result of data averaged from (10) 3 hour averaging periods per the TGR SCN-3 specifications.

#### D.1.7 Fractional Frequency Stability

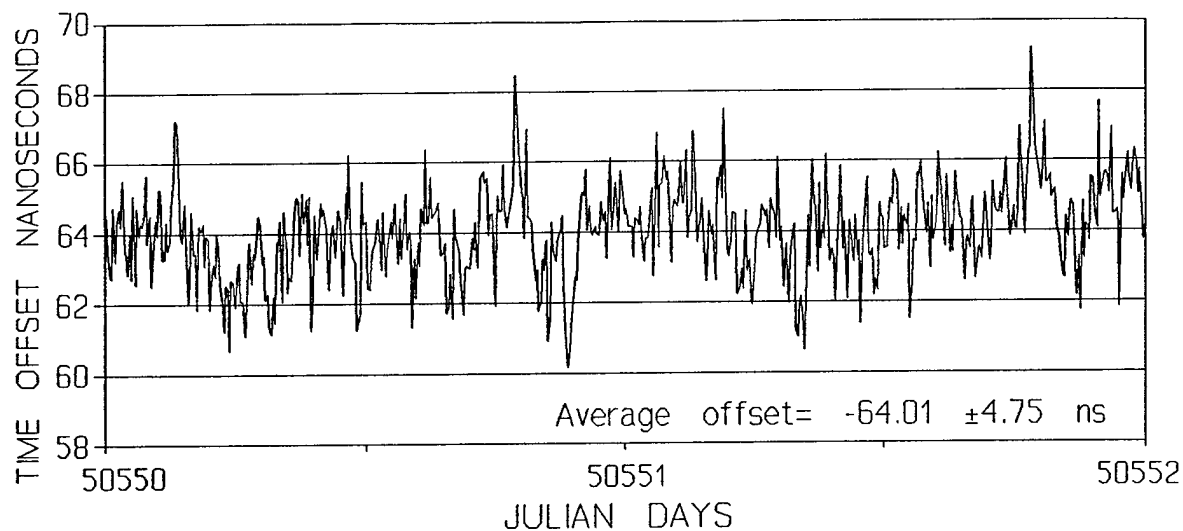
Phase data was taken from the 5 MHz sine wave output at one second intervals for one hour and at one hour intervals over 64 days for both using a regular coax cable (copper) and a fiber optic cable (fiber). These data sets were used to calculate the Allan Deviation,  $\sigma_y(\tau)$ , for sample periods of between 1 and 500,000 seconds with the results given in figures D.15 and D.16. The noise introduced by the fiber optic antenna cable gives a slightly higher Allan Deviation than the copper connected antenna cable. Figure D.17 is the Allan Deviation of the Truetime, Inc. MK III unkeyed timing receiver which does not satisfy the TGR specifications over one portion of the curve. The MK-V receiver met all the TGR frequency stability specifications.

#### D.1.8 Conclusions

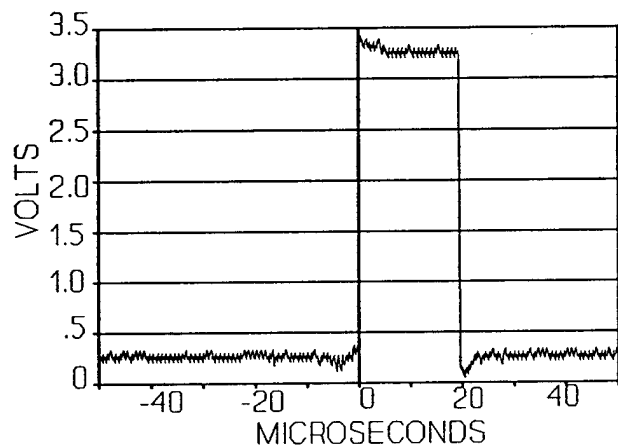
The Truetime MK-V tested at NRL was found to meet all of the TGR time and frequency performance specifications. The Truetime MK-V one pulse per second time output was found to be lagging GPS time by  $64.01 \pm 4.75$  nanoseconds. Once calibrated the MK-V could output the correct time to within  $\pm 10$  ns after a few minutes of averaging time. The TGR specifications requires a 10 volt peak level for the one pulse per second signal whereas the MK-V produced only a TTL pulse which is not considered serious. The MK-V phase noise floor was below the TGR specification except between 100 to 1000 Hz and is not considered to be significant.

For long antenna runs or for electrical isolation, the fiber optic cable offers a good solution. It introduces very little noise into the system and much easier to install into isolated electro-magnetic shielded systems.

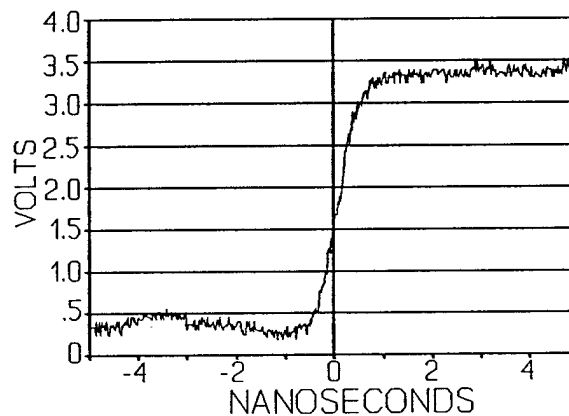
While still not meeting all of the original TGR specifications the Truetime MK-V should still make a good replacement for the Loran-C receivers. The Truetime MK-V is a solution due the fact that the DOD may require that all GPS receivers used be PPS-Y code capable in the near future.



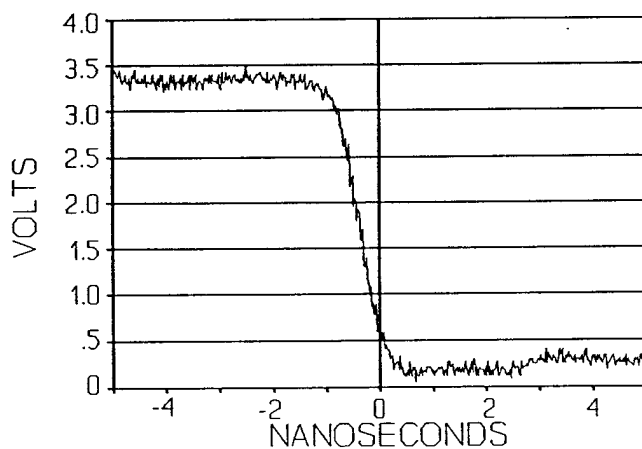
**Figure D.1 True Time MK-V receiver time error VS USNO(MC2)**



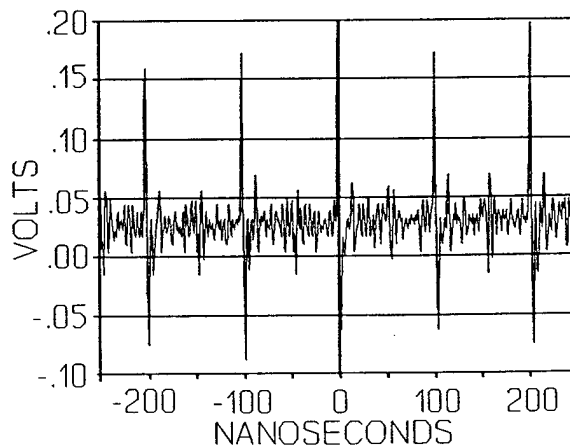
**Figure D.2. 1PPS output.**



**Figure D.3. Rise time of 1PPS.**



**Figure D.4. Fall time of 1PPS.**



**Figure D.5. Noise on 1PPS.**

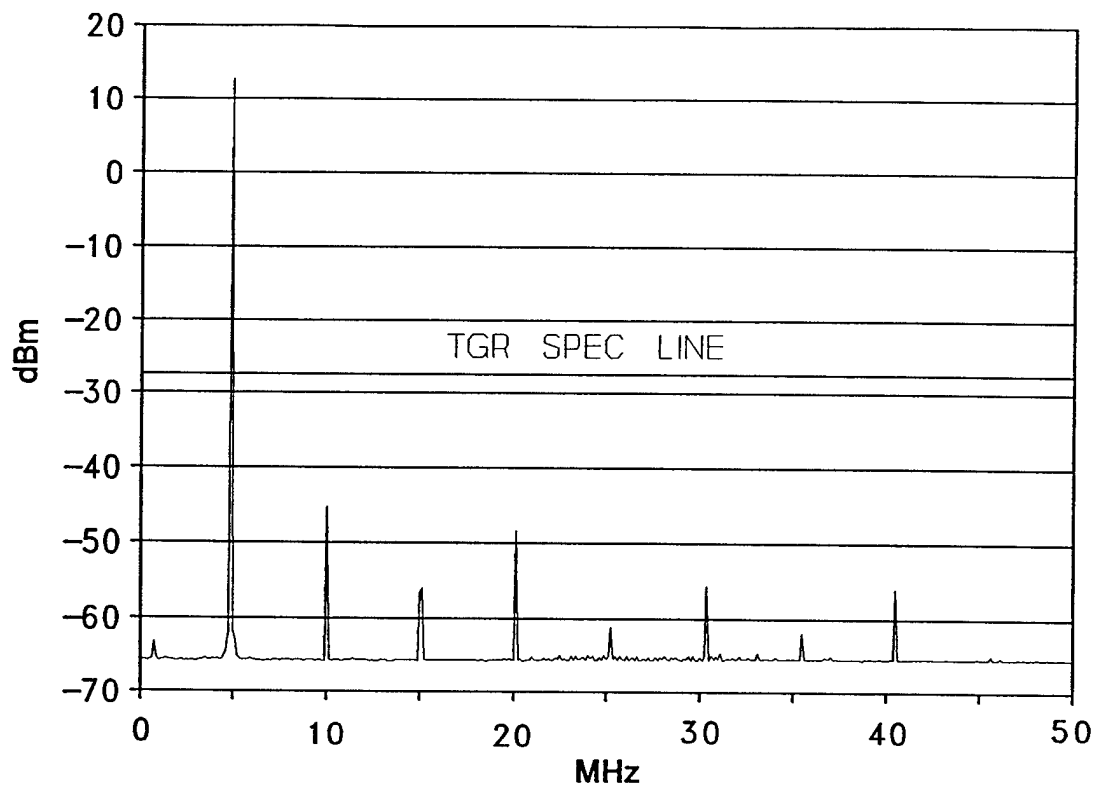


Figure D.6. 5 MHz output spectrum with harmonics to 50 MHz.

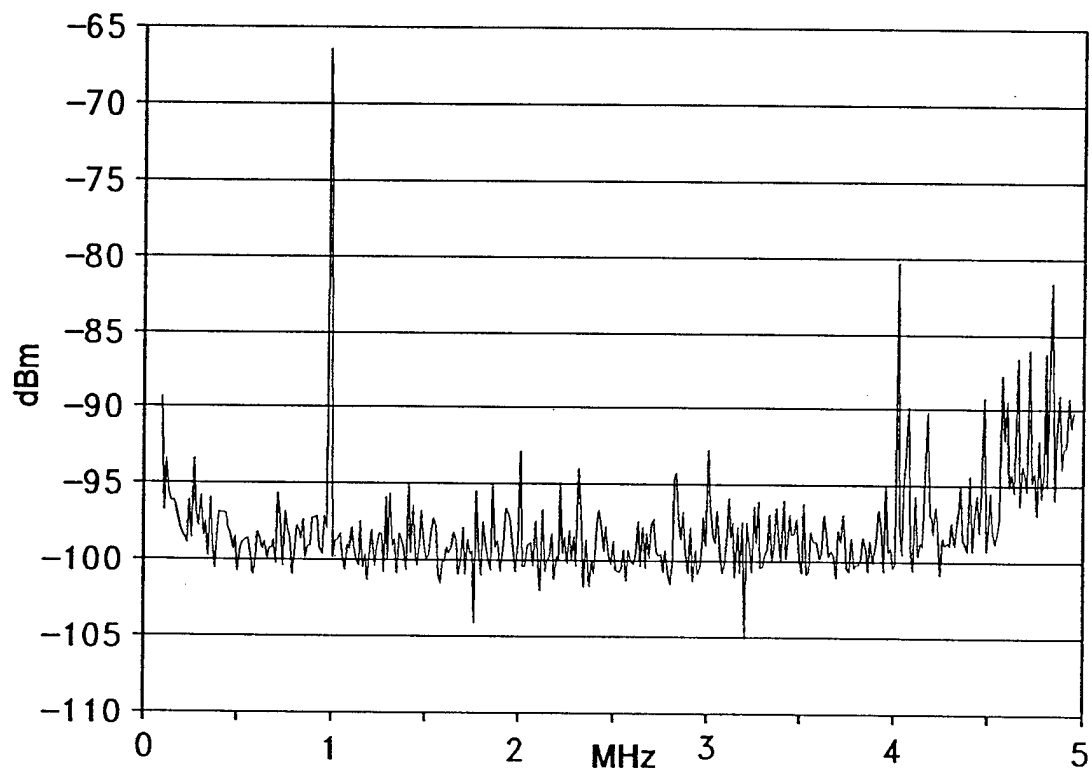


Figure D.7. 5 MHz output spectrum from 100 KHz to 4.95 MHz with 1/4 wave trap at 5 MHz.

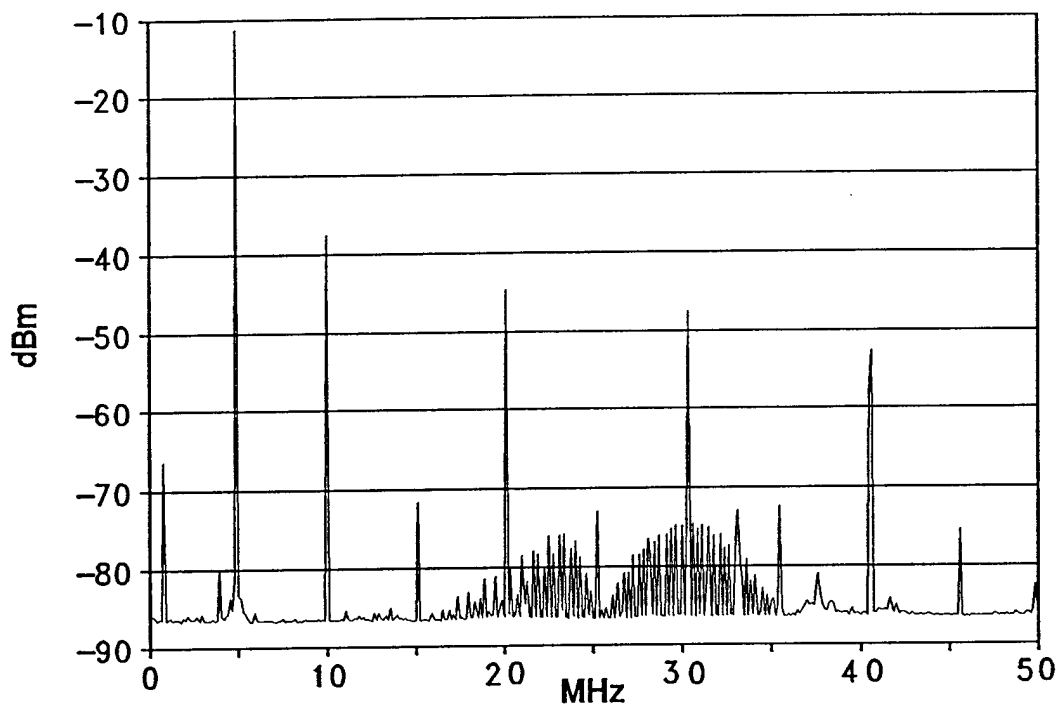


Figure D.8. 5 MHz output spectrum to 50 MHz with a 1/4 wave trap at 5 MHz.

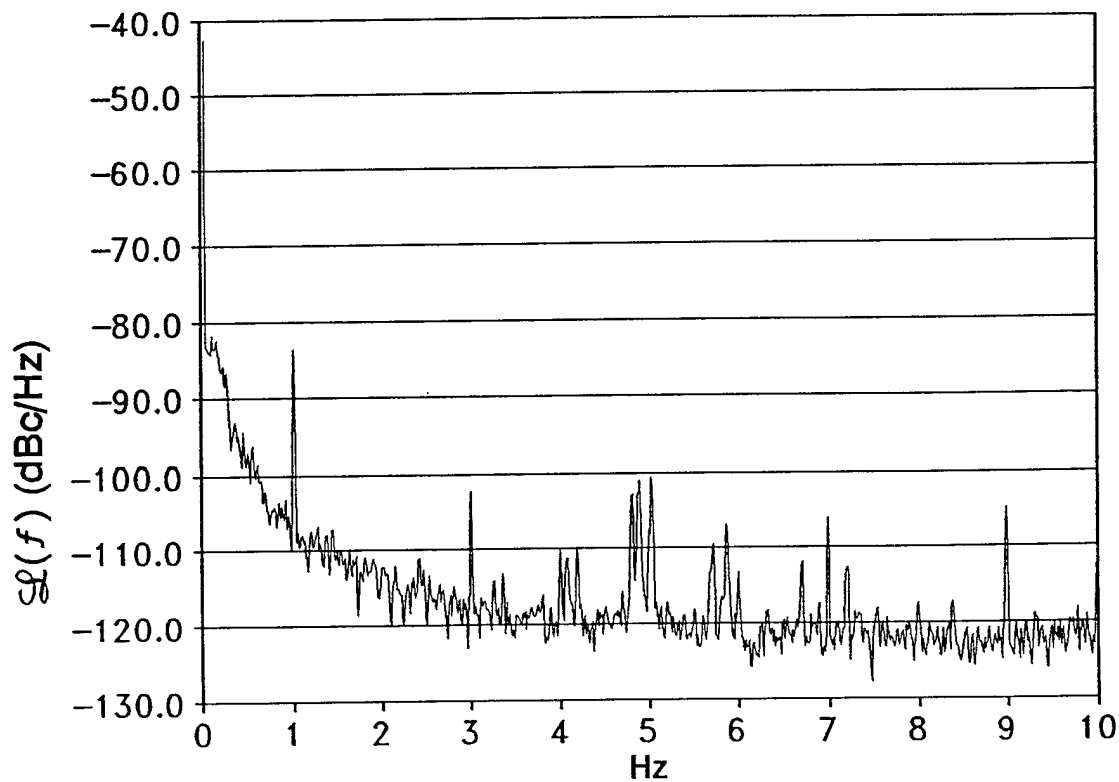


Figure D.9. Phase noise to 10 Hz from the 5 MHz output with the fiber optic antenna cable connected.

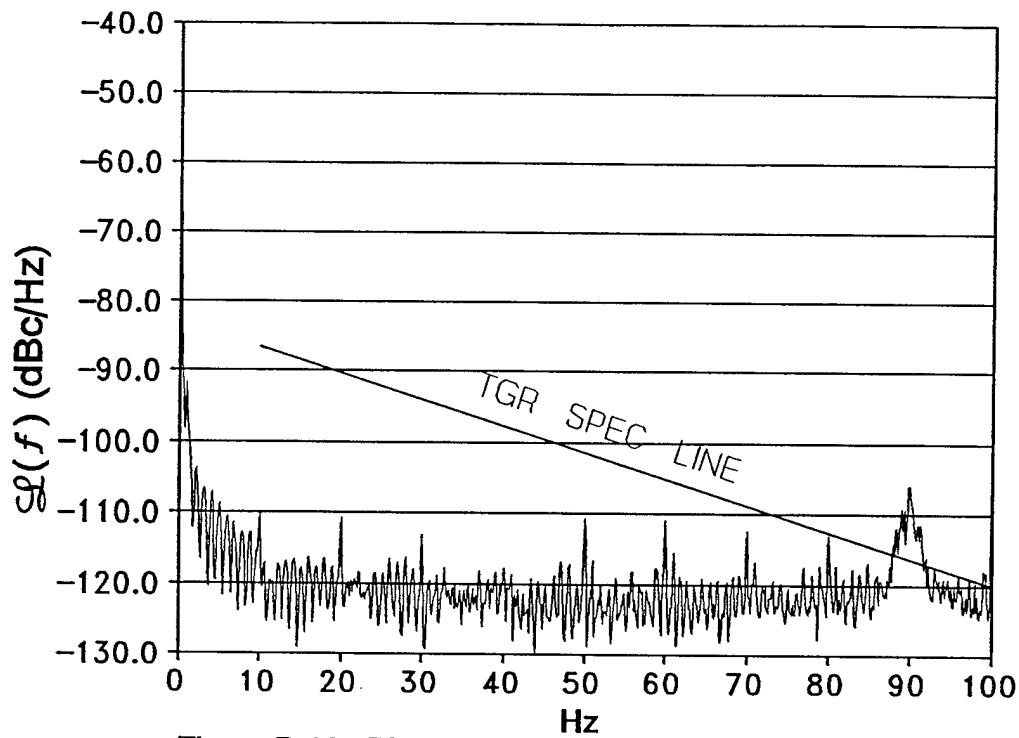


Figure D.10. Phase noise to 100 Hz from the 5 MHz output.

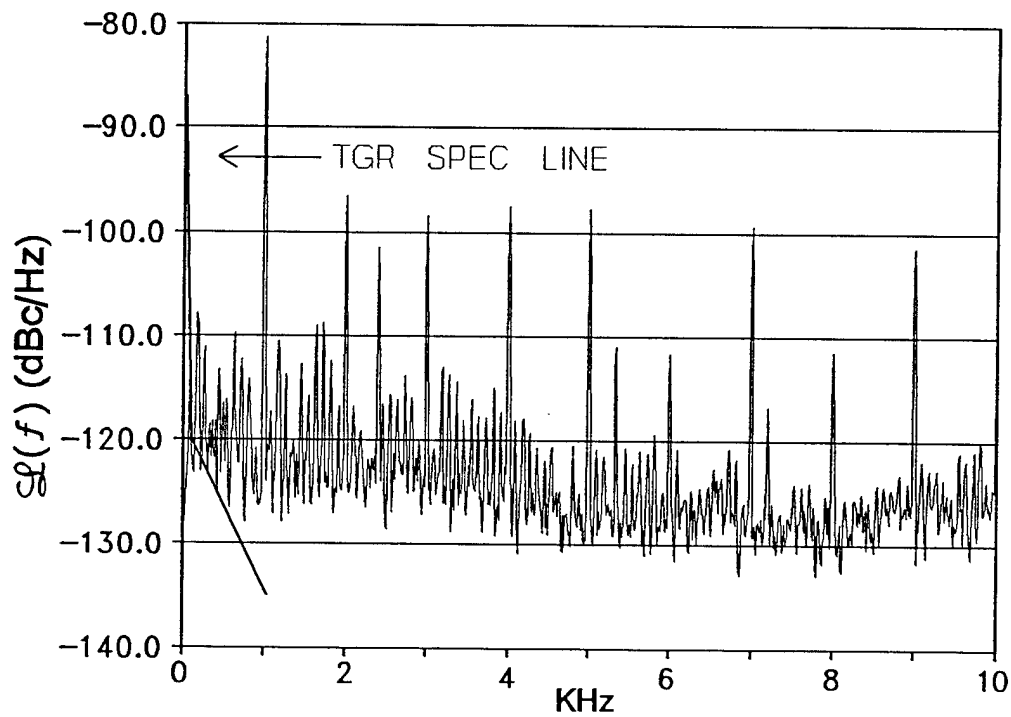


Figure D.11. Phase noise to 10 KHz from the 5 MHz output.



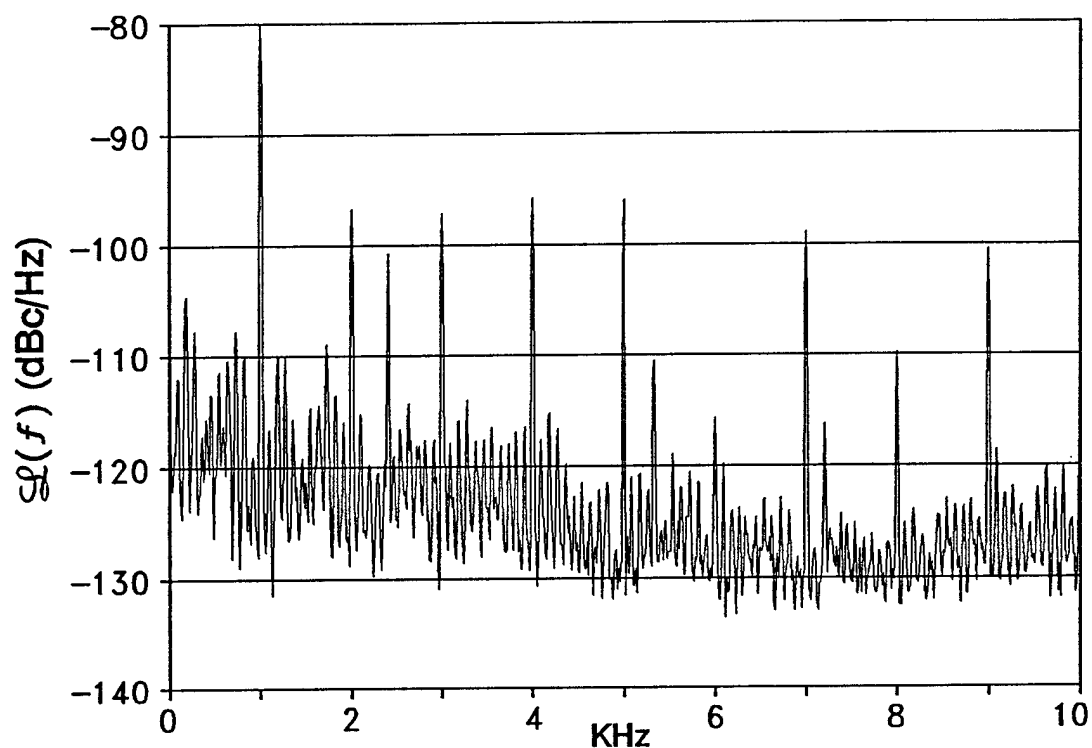


Figure D.12. Phase noise to 10KHz from the 5 MHz output with the fiber optic antenna cable connected.

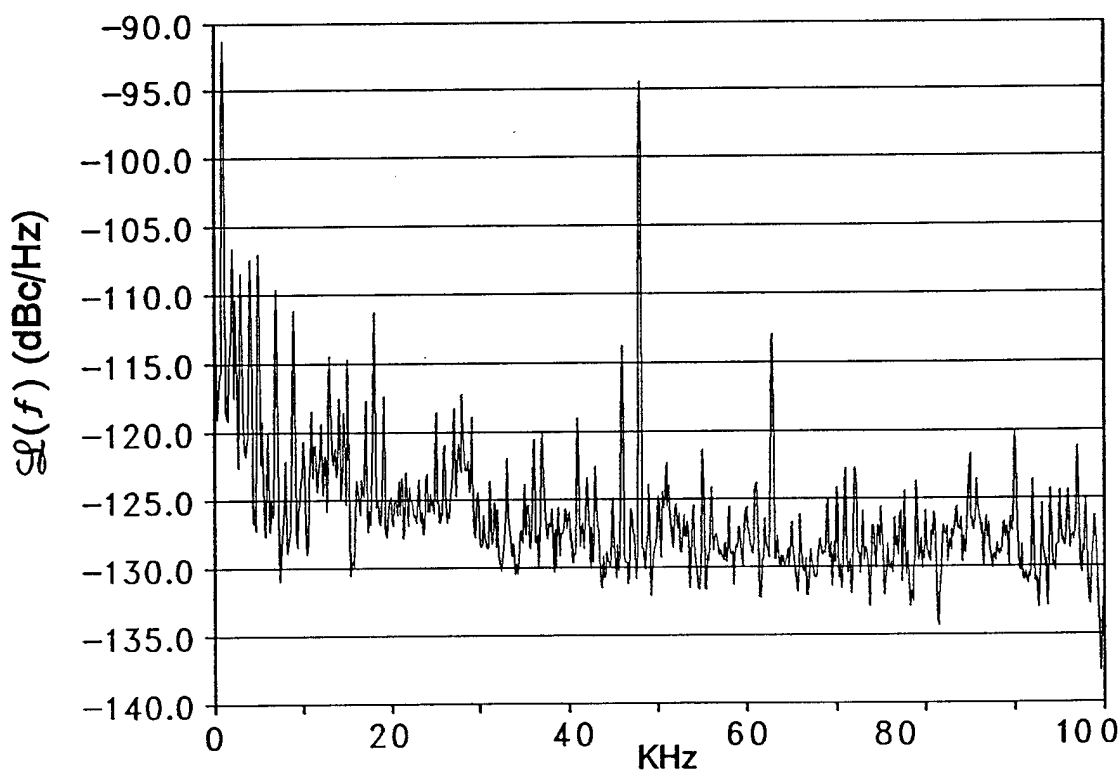


Figure D.13. Phase noise to 100 KHz from the 5 MHz output.

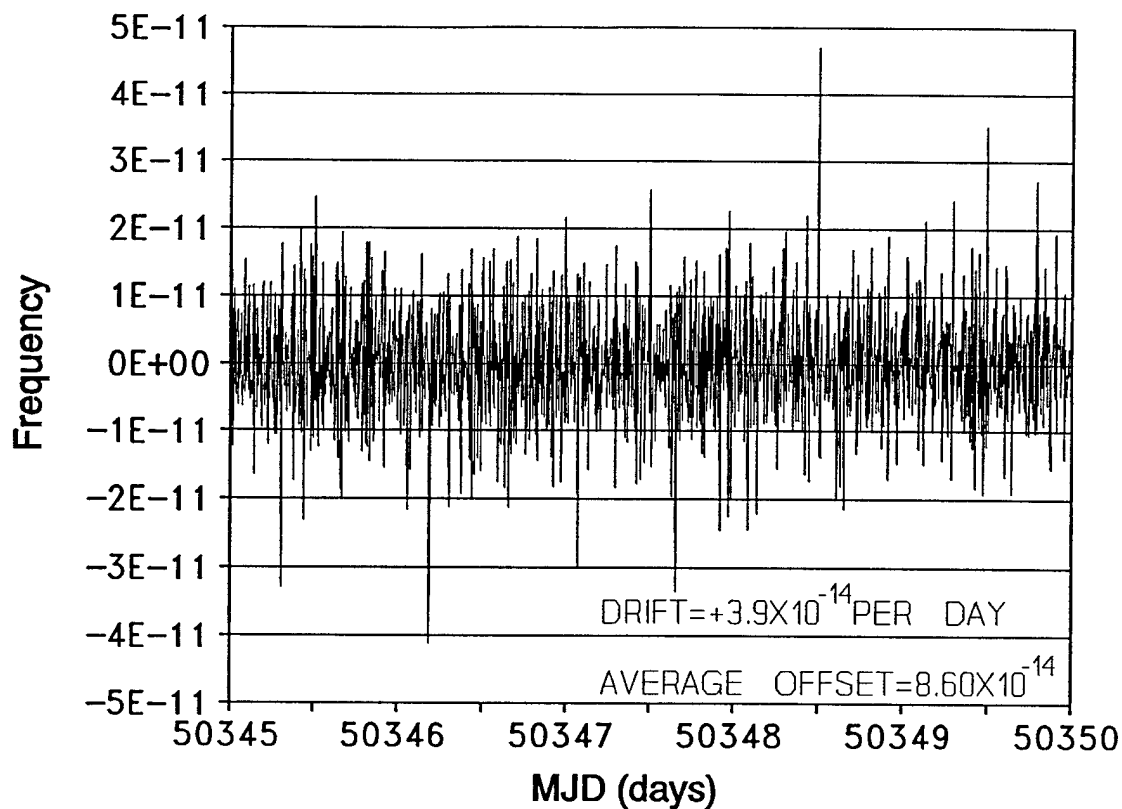


Figure D.14. Frequency data from the receiver's 5 MHz output.

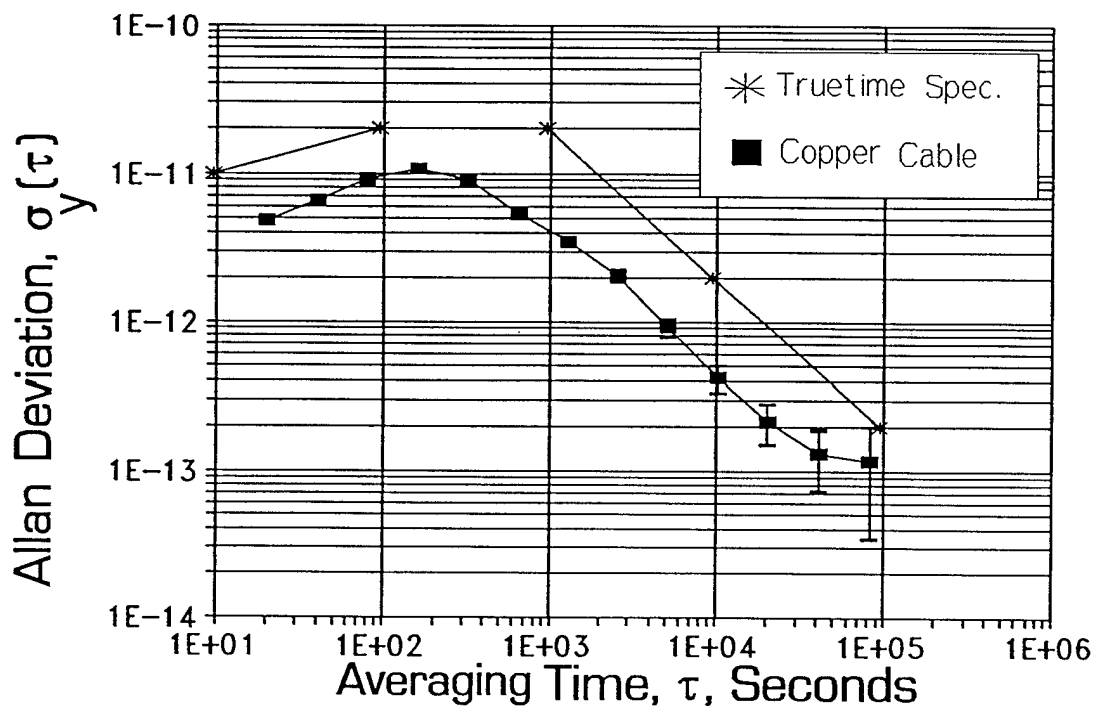


Figure D.15. Allan Deviation using a copper cable from the antenna to the receiver.

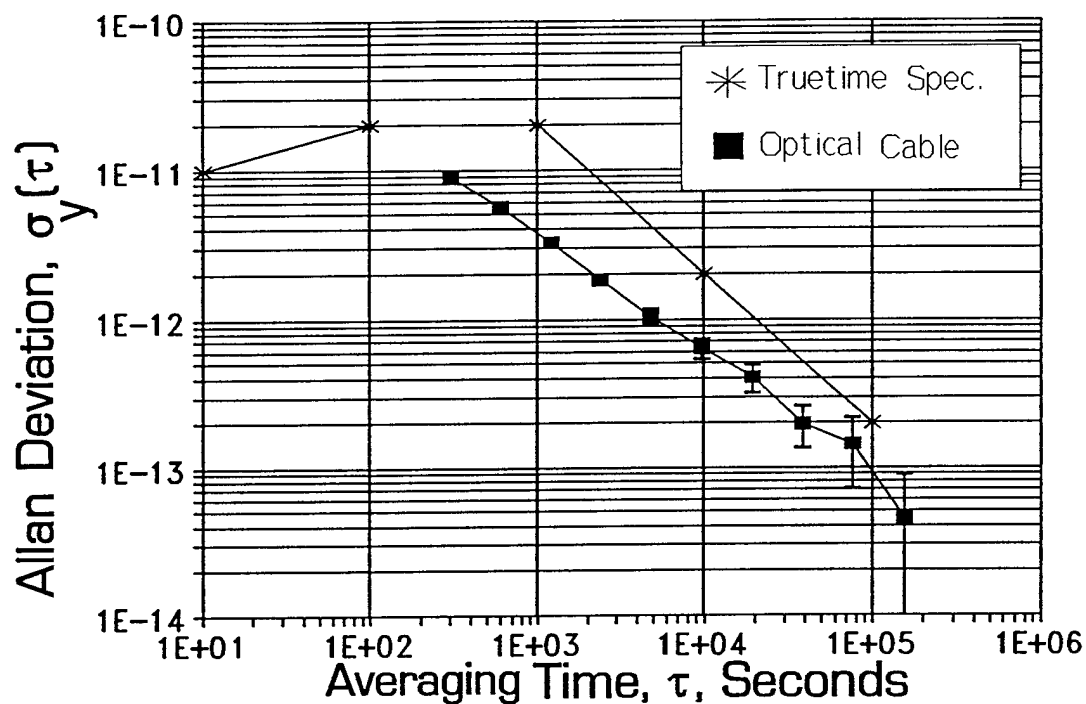


Figure D.16. Allan Deviation using a fiber optic link between the antenna and receiver.

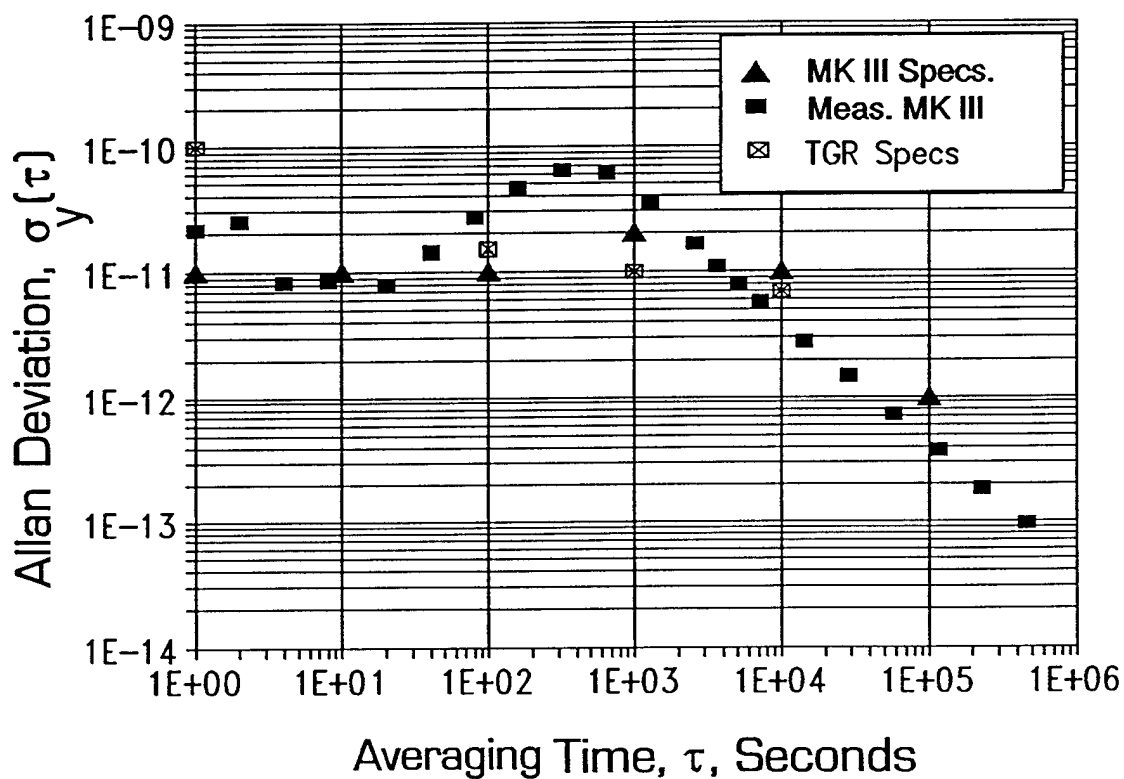


Figure D.17. Allan Deviation plot of the frequency data and specifications of the unkeyed Truetime MK III receiver.

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